TIME-LAPSE MODELING AND INVERSION OF CO2 SATURATION FOR SEQUESTRATION AND ENHANCED OIL RECOVERY

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ABSTRACT

In this quarter we concluded Phases II and III of the project. In Phase II we developed a practical seismic modeling workflow and algorithms to simulate the prestack seismic (AVO) response of CO_2 injection (both miscible and immiscible) by means of 1D well-log modeling. In Phase III we researched and developed new technology to perform quantitative inversions of time-lapse 4D seismic data to estimate injected CO_2 distributions within selected reservoir zones. Using the Sleipner dataset, we generated a suite of AVO responses over a range of temperatures and CO_2 saturations, and then extracted time-lapse seismic attribute maps of traveltime and amplitude changes from the sand wedge at the top of the reservoir. The seismic attributes were then inverted to yield CO_2 saturation and temperature values. The inversion algorithm was not able to discriminate between different temperature scenarios because of the lack of sensitivity of the time-lapse attributes on temperature; consequently, only maps of CO_2 thickness and its standard deviation were generated for the top layer. From this information we estimated that 7% of the total CO_2 injected over a five-year period had reached the top of the reservoir. This estimate is approximately equal to the ratio of the area of the seismic amplitude anomaly from the topmost layer to the total area of all amplitude anomalies seen in the reservoir.

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I. EXECUTIVE SUMMARY

In this reporting period we concluded Phases II and III of the project. In Phase II we developed a practical seismic modeling workflow and algorithms to simulate the prestack seismic (AVO) response of CO_2 injection (both miscible and immiscible) by means of 1D well-log modeling. In Phase III we researched and developed new technology to perform quantitative inversions of time-lapse 4D seismic data to estimate injected CO_2 distributions within selected reservoir zones. The inversion algorithm works by first generating synthetic time-lapse changes in seismic attributes over a range of selected reservoir parameters using the seismic modeling workflow developed in Phase II.

Using the Sleipner dataset, we generated a suite of AVO responses over a range of temperatures and CO_2 saturations, and then extracted time-lapse seismic attribute maps of traveltime and amplitude changes from the sand wedge at the top of the reservoir. The seismic attributes were then inverted to yield CO_2 saturation and temperature values. The inversion algorithm was not able to discriminate between different temperature scenarios because of the lack of sensitivity of the time-lapse attributes on temperature; consequently, only maps of CO_2 thickness and its standard deviation were generated for the top layer. From this information we estimated that 7% of the total CO_2 injected over a five-year period had reached the top of the reservoir. This estimate is approximately equal to the ratio of the area of the seismic amplitude anomaly from the topmost layer to the total area of all amplitude anomalies seen in the reservoir.

II. EXPERIMENTAL

No experimental methods were used during this reporting period.

III. RESULTS AND DISCUSSION

In Phase II we developed a practical seismic modeling workflow and algorithms to simulate the prestack seismic (AVO) response of CO_2 injection (both miscible and immiscible) in a subsurface porous aquifer/reservoir. The workflow requires the integration of geologic properties, well log data, laboratory core measurements and fluid information, and engineering field data (such as well pressure, saturations, and CO_2 injection rates) acquired at different production times. These data are then used to derive the fluid-saturated bulk moduli, shear moduli, and densities for a particular horizon of interest in the reservoir, and for a particular set of CO_2 injection scenarios, using the tools developed in Phase I. The moduli and densities directly yield the P- and S-velocities, which, along with the densities, are used to simulate offset-dependent P-wave seismic amplitudes by means of 1D well-log modeling. A suite of synthetic datasets were generated for different scenarios of CO_2 saturation and temperature. These data were subsequently used in the inversion procedure of Phase III.

In Phase III we researched and developed new technology to perform quantitative inversions of time-lapse 4D seismic data to estimate injected CO_2 distributions within subsurface reservoirs and aquifers. The algorithm works by first generating synthetic time-lapse changes in seismic attributes over a range of selected reservoir parameters, such as CO_2 saturation and temperature, using the seismic modeling workflow developed in Phase II. Next we extracted time-lapse seismic attribute maps of traveltime and amplitude from the uppermost layer at Sleipner and used them as input data for the CO_2 inversion. The seismic attributes were then inverted using the synthetic forward modeled data to yield CO_2 saturation and temperature values. The inversion algorithm was not able to discriminate between different temperature scenarios because of the lack of sensitivity of the time-lapse attributes to temperature. As a consequence, only maps of CO_2 thickness and its standard deviation were generated for the top reservoir layer (see Appendix A). From this information we estimated that 7% of the total CO_2 injected over a five-year period had reached the top of the reservoir. This estimate is approximately equal to the ratio of the area of the seismic amplitude anomaly from the topmost layer to the total area of all amplitude anomalies seen in the reservoir.

IV. CONCLUSIONS

In this quarter we concluded Phases II and III of the project. In Phase II we developed a practical seismic modeling workflow and algorithms to simulate the prestack seismic (AVO) response of CO_2 injection (both miscible and immiscible) by means of 1D well-log modeling. In Phase III we researched and developed new technology to perform quantitative inversions of time-lapse 4D seismic data to estimate injected CO_2 distributions within selected reservoir zones. Using the Sleipner dataset, we generated a suite of AVO responses over a range of temperatures and CO_2 saturations, and then extracted time-lapse seismic attribute maps of traveltime and amplitude changes from the sand wedge at the top of the reservoir. The seismic attributes were then inverted to yield CO_2 saturation and temperature values. The inversion algorithm was not able to discriminate between different temperature scenarios because of the lack of sensitivity of the time-lapse attributes on temperature; consequently, only maps of CO_2 thickness and its standard deviation were generated for the top layer. From this information we estimated that 7% of the total CO_2 injected over a five-year period had reached the top of the reservoir. This estimate is approximately equal to the ratio of the area of the seismic amplitude anomaly from the topmost layer to the total area of all amplitude anomalies seen in the reservoir.